Semantic Working Memory Predicts Relative Clause Sentence Comprehension: A Case Series Approach

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Abstract

Sentence comprehension involves simultaneous processes such as maintaining and integrating different types of verbal representations. As such, it has been argued that sentence comprehension relies on working memory (WM). Some findings suggest that semantic (word meaning) WM rather than phonological (speech sound) WM is critical for comprehension. This study took a case-series multiple regression approach to examine the relationship between sentence comprehension and WM for 56 individuals with aphasia. We examined the independent contribution of phonological and semantic WM in predicting comprehension for higher WM target sentences relative to matched lesser WM sentences, while also controlling for single word processing. We found that only semantic WM had a significant contribution to comprehension for three contrasts. However, for the fourth contrast of trials requiring syntactic processing with those requiring only lexical processing, both WM contributions were significant. The possible backup role of phonological WM for comprehension of role reversals is discussed.

Keywords: Language comprehension; working memory; cognitive neuropsychology

Introduction

Language comprehension involves the active maintenance, processing, and integration of verbal information. Thus, sentence comprehension has been argued to draw on working memory (WM) resources (see Zahn, Horne & Martin, in press for review). For instance, consider the processes involved in understanding this object relative sentence, "*The boy that the girl carried had red hair"* (Martin, 1987). Arguably, comprehension requires individuals to maintain "*boy"* in WM through the end of the embedded clause to link as the object of "carried" and also through the end of the sentence to link as the subject of "*had red hair*" (Gibson, 1998). To the extent that comprehension draws on WM capacity, one would predict that those with greater capacity would show better comprehension, particularly for sentences making the most demands on WM. In the present study, we assessed people with aphasia who have varying degrees of WM deficits, examining the relation of their WM capacity to comprehension for various types of relative clause sentences.

In assessing WM, we took the domain-specific WM approach. In contrast to standard models of verbal WM that propose only a single phonological WM buffer for verbal information (Baddeley, Hitch & Allen, 2021), the domain-specific model proposes separate buffers for phonological (i.e., speech sound) and semantic (i.e., word meaning) information. Patients with a phonological WM deficit have difficulty with tasks requiring phonological maintenance such as the rhyme probe task, in which they have to judge whether a probe word rhymes with a word in a preceding list (e.g., list: vat, eye, cheer, trace, probe: rat). Patients with a semantic WM deficit have difficulty with tasks requiring semantic maintenance, such as the category probe task in which they judge whether a probe word is in the same semantic category as a list word (e.g., list: *table, sign, daisy, bear*, probe: rose).

Previous work has shown a constellation of symptoms differentiating patients with phonological vs. semantic WM deficits (Martin, 2021, Martin, Lesch & Bartha, 1999; Martin, Shelton & Yaffee, 1994). Those with phonological WM deficits have difficulty maintaining phonological information and fail to show standard phonological effects on span (i.e., word length and phonological similarity), at least with visual presentation, whereas those with semantic WM deficits do show these phonological effects. Patients with a phonological WM deficit perform better on tasks requiring the maintenance of visually presented words compared to auditorily presented words, the reverse of the pattern for controls and those with semantic WM deficits. Phonological WM deficit patients also showed worse performance on the rhyme probe than category probe task, whereas semantic WM deficit patients showed the reverse pattern of performance. Finally, those with a phonological WM deficit show better performance on word than nonword lists, in line with controls, whereas those with semantic WM deficits do not show this advantage, arguably because they do not benefit

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from the semantic information in words. This neuropsychological evidence for distinct phonological and semantic WM buffer deficits is not explained by models of WM that propose only a single verbal WM buffer for phonological information, and thus this evidence provides support for the domain specific model of WM (Martin, Rapp & Purcell, 2020; Zahn et al., in press).

Work investigating the relationship between WM and sentence comprehension has often used relative clause sentences with a center-embedded structure, in which a relative clause intervenes between the head noun and the main clause verb phrase (e.g., "The boy that had red hair carried the girl") (e.g., Caplan, Waters, DeDe, Michaud & Reddy, 2007). However, such prior studies have focused on measures of phonological WM. In the present study, we extend these previous findings by examining the possibly distinct contributions of semantic and phonological WM in relative clause comprehension. In our sentence comprehension task, participants heard a sentence with an action clause and a descriptive clause (see Table 1) and then had to choose between two pictures the one that matched the sentence. For the critical trials requiring syntactic processing for picture choice, the incorrect picture either reversed the role of the two nouns with respect to the action verb (boy carrying girl vs. girl carrying boy) or reversed the entity described by the descriptive clause (the boy vs. the girl had red hair). Other trials employed lexical distractor pictures where a different noun, verb, or descriptive term (e.g., blonde hair) was depicted in the incorrect picture. As shown in Table 1, five types of sentences were used which varied in terms of the processing demands of the relative clause and main clause. For types 1 and 2, both the main and embedded clauses had an active structure, but they differed in whether the reversible action clause was the main or embedded clause. For types 3 and 4, the reversible action clause was in a passive form, and appeared in the main clause in type 3 and in the embedded clause in type 4. Type 5 had an object relative form. Many prior studies in the literature have focused on subject and object relative forms like those in types 2 and 5, given that they are closely matched except for the word order in the embedded clause (Traxler, Morris, & Seely, 2002). The object relative form potentially makes greater demands on WM, as the role of the head noun in the embedded clause cannot be determined until processing the embedded clause subject and verb, when its role as the direct object of the verb can be determined. In the subject relative form, the head noun does not have to be maintained as long because its role in the embedded clause can be determined as soon as the verb is processed. Thus, one contrast of interest was comprehension for the object (type 5) vs. subject (type 2) relative clauses. Three other contrasts were also assessed. One was between the sentences with a passive form in one clause (types 3 and 4) vs. those with active forms for both clauses (types 1 and 2). Passive forms are more difficult to comprehend (Bever, 1970; Ferreira, Bailey, & Ferraro, 2002), and thus one might anticipate greater WM demands for sentences with passives, potentially because of the slower processing time for passives prior to the integration of sentence elements. Another contrast was between the sentences with a passive in the embedded clause (type 4) and a passive in the main clause (type 3), given that embedded clauses are generally more difficult to process (e.g., Barry & Lazarte, 1995) and embedded passive clauses should be particularly difficult. A final contrast was between mean performance on all five sentence types for the trials tapping syntactic processing vs. those tapping lexical processing. This contrast should reveal the relation to WM from the overall need to carry out syntactic analysis vs. simple retention of lexical information. Thus, in this study we examined these four sentence contrasts and determined if they related to semantic or phonological WM capacity.

Table 1: Relative clause sentences.

Structure of action clause	Example
1) Main clause active	The boy that had red hair carried the girl.
2) Embedded active	The boy that carried the girl had red hair.
3) Main clause passive	The boy that had red hair was carried by the girl.
4) Embedded passive	The boy that was carried by the girl had red hair.
5) Object relative	The boy that the girl carried had red hair.

Prior neuropsychological research has generally supported the claim that semantic but not phonological WM is critical for sentence comprehension. An early study on the role of WM in sentence comprehension by Martin (1987) showed that a patient with very reduced phonological WM capacity generally performed well on active and passive transitive sentences and complex relative clause sentences like those in Table 1 but did show some impairment for the most difficult sentence types (types 4 and 5). However, later case studies reported individuals with phonological WM deficits who performed at a high level on these same difficult structures (Butterworth Campbell & Howard, 1986; Waters, Caplan, & Hildebrandt, 1991). Nonetheless, some recent group studies of individuals with aphasia have reported correlations between phonological WM and complex sentence comprehension (Pettigrew & Hillis, 2014; Varkanitsa & Caplan, 2018), though these studies have not typically differentiated between phonological and semantic WM, and performance on the two types of WM tasks is correlated (see Martin & Schnur, 2019).

More consistent evidence relates semantic WM deficits to deficits in sentence comprehension (Martin et al., 1994; Martin & He, 2004). For instance, patients with a semantic WM deficit have more difficulty in sentence comprehension when the syntactic structure of a sentence does not allow for the meaning of the words to be integrated immediately. In Martin & He (2004), two patients with semantic WM deficits performed poorly in detecting the anomaly in sentences such as *rugs, vases, and mirrors cracked during the move* (AB= 40% error; ML = 38% error), where the nouns must be held in semantic WM until the verb is heard and processed. The semantic WM patients performed much better for sentences like *the movers cracked the mirrors, vases, and rugs* (AB = 19% error; ML= 18% error), where the nouns could be immediately integrated with the verb *cracked* as they were heard. A patient with a phonological WM deficit performed well on both kinds of sentences, showing an effect of delayed integration similar to that of controls.

Semantic WM is also related to interference resolution in comprehension (Tan & Martin, 2018; Tan, Martin, & Van Dyke, 2017). Tan & Martin (2018) manipulated semantic and syntactic interference in sentences and analyzed accuracy in comprehension of these sentences in relation to participants' semantic WM, phonological WM and executive functioning. According to the cue-based parsing theory of sentence comprehension, when integrating lexical items, such as a verb and its subject, interference arises from overlap between the retrieval cues associated with items, such as verbs, and the semantic or syntactic features of other lexical items in the sentence that could potentially be integrated with the verb. Examples of these sentence types can be seen in Table 2. There is semantic interference in the LoSyn/HiSem sentence type because the noun in the embedded clause, *champion*, is a noun that is semantically plausible as the subject for the verb *win* while *record*, from the LoSyn/LoSem sentence is not because it is an inanimate object. In the high semantic interference sentence, the partial match between the verb and the semantic features of the embedded noun *champion* causes semantic interference when integrating the main verb with its subject. The noun in the embedded clause in the HiSyn/LoSem interference condition is a grammatical subject, making it a partial match for integration as the subject of the main verb. In the LoSyn/LoSem interference condition, the embedded noun is a direct object and not a partial match for the subject of the main verb of the sentence. It was found that semantic WM capacity, but not phonological WM capacity, was related to participants' ability to resolve semantic interference. Neither semantic nor phonological WM capacity was related to the ability to resolve syntactic interference (Tan & Martin, 2018; Tan, Martin, & Van Dyke, 2017).

In the current study, we investigated the relationship between relative clause sentences comprehension and domain-specific WM while controlling for single word processing using a database containing results from a battery of language and cognitive measures for 56 people with chronic aphasia. As noted earlier, while many studies have carried out examinations of the relation of WM capacity to relative clause comprehension in individuals with aphasia (e.g., Waters et al., 1991; Caplan & Waters, 1999; Varkanitsa & Caplan, 2018), this work has not separated out the relation to phonological versus semantic WM. Prior studies from Martin and colleagues (e.g., Martin & Romani, 2004; Tan & Martin, 2018) demonstrating that those with semantic WM deficits have difficulties in maintaining information across some distance and in interference resolution would strongly imply that difficulties with relative clause comprehension should be observed. That is, as discussed earlier, center-embedded relative clause sentence makes strong demands on retaining information prior to integration. Also, semantic and syntactic interference would be present in such sentences. For example, when processing the main clause verb and attempting to find its subject, there would be semantic interference from the reversible entity in the embedded clause. There would also be syntactic interference as both nouns are subjects. We predicted that patient's semantic WM capacity, but not phonological WM capacity, would have an independent contribution in predicting sentence comprehension of relative clause sentences when contrasting sentence types with greater or lesser WM demands or greater or lesser interference (Martin, 1987; Martin et al., 1994; Martin & He, 2004, Tan & Martin, 2018). To rule out difficulties with understanding individual words as the source of WM or sentence comprehension difficulties, we controlled for the patients' single word phonological and semantic processing abilities. The present study is unique in contrasting the relation of semantic and phonological WM capacities to comprehension of difficult relative clause structures. The study is also unique in that we control statistically for single word processing abilities. Previous studies have attempted to address the role of single word comprehension and production in sentence comprehension, but these attempts may have been inadequate. Past research has not separated single word processing at the semantic and phonological levels and has not included these processing measures as controls in their analysis but rather as screening measures to examine when comparing high and low performers on sentence comprehension (Caplan et al., 2007).

Table 2: Semantic and syntactic interference sentences (adapted from Tan and Martin, 2018)

Sentence type	Example
LoSyn/LoSem	The jockey who had challenged the unbeatable record yesterday will win.
LoSyn/HiSem	The jockey who had challenged the unbeatable champion yesterday will win.
HiSyn/LoSem	The jockey who claimed that the record was unbeatable yesterday will win.
HiSyn/HiSem	The jockey who claimed that the champion was unbeatable yesterday will win.
Question	*Will the jockey win?*

Note. "Lo-" and "Hi-" refer to low and high interference conditions, and "-Syn" and "-Sem" refer to syntactic interference and semantic interference conditions.

Methods

Participants

The 56 participants were individuals with chronic aphasia from a database collected over the span of 15 years. Mean age was 62 years (SD = 14) and mean education was 16 years (SD=2.5). Twenty-two participants were female, and forty-four were right-handed.

Materials

Single word processing A single word - single picture matching task was used in which patients had to indicate if a spoken word matched the picture (Martin et al., 1999). Across separate trials, the pictures were paired with the correct word (e.g., CAT/cat), a semantic foil (e.g., CAT/dog), a phonological foil (e.g., CAT/hat), or an unrelated foil (e.g., CAT/nail). The semantically related trials used words from the same semantic category whereas the phonologically related foils differed by one phoneme from the target. Participants were asked "Is this a __?" and had to indicate if the picture matched the word or not. Performance on the semantically related and phonologically related foils was compared to that for the matching trials to compute d' measures for each (d' semantic and d' phonological).

The pyramids and palm trees (PPT; Howard & Patterson, 1992). task was also used to assess semantic processing. In the PPT, three pictures are presented with one at the top and two below. Subjects indicate which of the two bottom pictures is most closely related to the top picture (e.g., top picture = pyramid; bottom pictures = palm tree, a fir tree; correct answer = palm tree). The PPT tests associative semantic knowledge.

Additional measures of phonological processing included consonant discrimination and auditory lexical decision (Martin et al., 1994). In the consonant discrimination task, the participant hears two single syllables. Non-matching syllables differ on a single distinctive feature of the consonant sound (e.g., "ba" "da"). Participants indicate whether the two sounds are the same or not. In the auditory lexical decision task, participants determine if a sound sequence they hear is an English word. The nonwords differed from a known word on one distinctive feature of a consonant (e.g., "baper" derived from "paper").

Composite semantic and phonological processing scores were calculated by determining the first principal component factor scores for the relevant semantic and phonological measures. Imputation was used if participants were missing one of the scores (N = 6). The semantic composite included the d' semantic measure from word-picture matching and the proportion correct on the PPT. The phonological processing composite included the d' phonological measure from word - picture matching, the proportion correct on the consonant discrimination task, and the proportion correct on the auditory lexical decision task.

Phonological WM Two tasks were used to tap phonological WM: the digit span task and the digit matching span task (Allport, 1984). In the digit span task, participants heard a list of numbers "5 7 1 4 3" and had to repeat the digits back in the correct order (M = 3.87, SD = 1.46, Range: 1-8.5). In the digit matching span task, participants heard two lists of digits, "2 4 5 6" and "2 5 4 6" and had to indicate if the two lists were the same or not (M = 4.08, SD = 1.38, Range: 0.56-6.5). On the non-matching trials, the second list reversed the order of two adjacent digits. These tasks are assumed to measure phonological WM because random lists of digits carry little semantic information and thus maintenance depends primarily on retention of phonological information. (Allen, Martin & Martin, 2012.) A phonological WM composite was computed by using factor scores from the first principal component combining these two measures. Imputation was used if patients were missing one of these scores (N = 8).

Semantic WM To measure semantic WM, we used the category probe task (Martin et al., 1994). In this task, participants heard a list of words (e.g., "table, pan, daisy, bear") followed by a probe word (e.g., "rose") and indicated if the probe word was in the same category as any of the words in the list (M = 2.40, SD = 1.38, Range: 0.42-6.5).

Sentence comprehension for sentence comprehension, we used the relative clause comprehension test that measures the accuracy of patients' sentence comprehension for each of the sentence types in Table 1.

As discussed in the introduction, participants heard a sentence and had to choose from two pictures the one that matched the sentence. There were 24 trials of each sentence type with reverse role distractor pictures and 18 trials with lexical distractors. We contrasted performance on sentence types having greater working memory demands to those with lesser working demands: 1) type 5 object relatives with type 2 subjects relatives, 2) the mean of the passive sentence types (types 3 & 4) with the active sentence types (types 1 and 2), 3) passive embedded clauses (type 4) with passive main clauses (type 3), and 4) the mean of all relative clauses for trials with reversal pictures vs. the mean for all types with lexical distractors.

Analysis

We used a case series approach to examine the relationship between semantic and phonological WM and relative clause sentence comprehension (Schwartz & Dell, 2010). This approach utilizes the continuous variation on the two WM capacities to predict relative clause sentence comprehension. This approach allows us to include a wide range of participants with various aphasia types and severity. This is warranted because previous studies have found little relationship between aphasia classification and patterns of performance on sentence comprehension (e.g., Caramazza et al., 2001; Prins et al., 1978).[1] Using multiple regression, we regressed performance on the more difficult sentence type of the contrast (e.g., object relatives) on the less difficult comparison sentence type (e.g., subject relatives), the

[1] A reviewer suggested that aphasia severity be included as a covariate in the models. However, severity as measured by the Aphasia Quotient (AQ) from the Western Aphasia Battery (Kertesz, 1982) was significantly correlated with the other predictors already included, particularly the semantic processing measure ($r = .74$, $p < .001$) and adding the AQ did not significantly improve the fit of any model (all p's > .28).

Table 3: Results of multiple regression analyses contrasting performance on sentences with greater WM demand against those with lesser demand.

	Coefficients and significance for WM predictors				Overall model		
Contrast	t	Beta	*SE*	*p*	F	*df*	*p*
Object relative (5) on active embedded (2)					16.03	5,55	<.0001*
Semantic WM	3.35	0.061	0.018	.002*			
Phonological WM	-0.23	-0.004	0.018	.82			
Passive composite (3+4) on active composite (1+2)					30.44	5, 55	<.0001*
Semantic WM	2.01	0.026	0.013	.049*			
Phonological WM	1.19	0.017	0.013	.24			
Embedded passive (4) on main clause passive (3)					13.96	5, 55	<.0001*
Semantic WM	2.20	0.040	0.018	.033*			
Phonological WM	0.58	0.011	0.018	.56			
Average of relative clause on lexical distractors					14.65	5, 46	<.0001*
Semantic WM	2.36	0.036	0.015	.023*			
Phonological WM	2.79	0.041	0.015	.008*			

Note. *Indicates significance at $p < .05$.

phonological and semantic WM measures, and the phonological and semantic single word processing composite measures. The significance of the coefficients (beta-weights) for each predictor in a multiple regression analysis reflects the contribution of that variable to predicting the outcome independent of the contribution of other variables in the model (Darlington, 1990). Thus, this analysis allows us to examine the contributions of phonological and semantic WM independent of each other and of single word processing abilities. Thus, we predicted that performance on the more difficult sentence type would increase as semantic WM capacity increased, while controlling for phonological WM and single word processing. In contrast, increases in phonological WM would not relate to increases in comprehension.

Results

The results of the regression analyses are shown in Table 3. The first four columns report statistics for the independent contribution of semantic WM (category probe) and the composite phonological WM measure (digit matching span and digit span) when controlling for the other WM measure and the single word processing measures. The last three columns report statistics for the whole regression model.

Object relative regressed on subject relative with active embedded relative clause

When regressing comprehension of the type 5 sentences (object relatives) on the type 2 sentences (subject relatives), the semantic WM measure (category probe) had a significant independent contribution ($\beta = 0.061$, $t(55) = 3.35$, $p = .002$. whereas phonological WM composite did not ($\beta = -0.004$, $t(55) = -0.23$, $p = .82$).

Passive composite regressed on active composite

In the regression of comprehension of the sentence types containing a passive (types 3 & 4) on matched sentence structures containing an active (types 1 & 2), the semantic WM measure had a significant independent contribution ($\beta = 0.026$, $t(55) = 2.01$, $p = .049$) whereas the phonological WM composite did not ($\beta = 0.017$, $t(55) = 1.19$, $p = .24$).

Embedded passive on main clause passive

In regressing comprehension of the sentences with an embedded passive (type 4) on the sentences with a main clause passive (type 3), the semantic WM measure of category probe had a significant independent contribution in predicting comprehension ($\beta = 0.040$, $t(55) = 2.20$, $p = .033$) whereas the phonological WM measure did not ($\beta = 0.011$, $t(55) = 0.58$, $p = .56$).

Relative clause mean regressed on lexical distractors

In the regression of mean comprehension across all sentence types (types 1-5) with reversal pictures on all sentence trials with lexical distractors, the semantic WM measure had a significant contribution ($\beta = 0.036$, $t(46) = 2.36$, $p = .023$) as did the phonological WM measure ($\beta = 0.041$, $t(46) = 2.79$, $p = .008$).

Discussion

This study represents the first case series analysis of the relation of relative clause sentence comprehension to semantic vs. phonological WM while controlling for single word processing. Based on prior results from studies varying the distance between words to be integrated (Martin & Romani, 1994: Martin & He, 2004; Hamilton, Martin & Burton, 2009) and studies manipulating semantic and syntactic interference (Tan & Martin, 2018; Tan, Martin & Van Dyke, 2017), we predicted that semantic WM, but not phonological WM, would have a significant independent contribution to the comprehension of relative clause sentences that theoretically place a higher demand on WM. For three of the four contrasts, this proved to be the case. The first contrast of object relatives vs. subject relatives showed a large and highly significant weight for semantic WM and an effect for phonological WM that was far from significance. The results suggest an important role for semantic WM in maintaining the meaning of the head noun across the interfering embedded clause subject noun to integrate with the embedded clause verb. The next two contrasts were motivated on the grounds that passive clause processing is more difficult – being slower and more error prone (Ferreira et al., 2002), with the result that information has to be maintained for longer while this difficult processing is carried out. Both of these contrasts of mean of main clause and embedded passives vs. mean of main clause and embedded actives and embedded passive vs. main clause passives also indicated a significant role for the ability to maintain semantic information while carrying out this difficult processing. This retention could involve maintaining the semantic representations of the head nouns prior to integration with both the main clause and embedded clause verbs. The second of these contrasts indicated that maintaining this information while processing an embedded passive clause resulted in a greater contribution of semantic WM than when the main clause was passive, which is consistent with the notion that processing of an embedded clause is generally more difficult, resulting in a longer time across which information must be retained. One might have predicted that phonological WM would be important in these contrasts, given that the word order for passives is unusual in terms of the ordering of agent and patient, and it is often argued that phonological WM is important for maintaining order information. However, as argued by McElree et al. (1993), the retention of the serial order of elements does not appear to be critical in sentence processing; rather, it is the retention of the derived interpretation of the roles of different elements as they are processed that is critical. For instance, for the type IV sentences, listeners may have assumed that the head noun is going to be the agent of both the main clause and the embedded clause; however, when processing the embedded clause passive structure (e.g., "was carried by"), this assumption has to be revised and this revision can be made as soon as the passive structure is processed. Once this is complete, the object of the embedded passive can be interpreted as the agent when it is processed.

Notably, however, for the final multiple regression analysis in which we regressed the average comprehension performance for all of the relative clause sentences with reversal distractor pictures vs. comprehension for those with lexical distractor pictures, we found that both phonological WM and semantic WM had independent contributions in predicting comprehension. While the results of this analysis provide additional support for the claim that semantic WM plays a critical role in the comprehension of relative clause sentences, they also indicate an unpredicted relation to phonological WM. Some have suggested that phonological WM may play a backup role (Miyake, Just, & Carpenter, 1994) allowing for a review of a sentence to check on the interpretation. However, one might have expected such a review to be more likely for more complex and uncommon structures (i.e., object relatives and passives); but, for the specific contrasts of more vs. less complex structures, the weight for phonological WM did not approach significance. The comparison of performance on trials with reversal distractor pictures and lexical distractor pictures contrasts trials where derivation of the syntactic structure is necessary to accurately perform the task vs. trials where it is not (i.e., when noting that an incorrect picture contains an entity, or a feature not mentioned in the sentence such as blonde hair vs. red hair). These results, which differ from those for the other multiple regressions, suggest that the role of phonological WM was equivalent across sentences with differing demands deriving from the complexity of their structures. Perhaps the tendency to use a backup phonological record to check the results of comprehension occurs for all sentence types because of the requirement to integrate the meanings of nouns, verbs, and adjectives – which is not required for the lexical distractor condition. This may be particularly the case where, as in the current study, there is the potential for the plausible reversal of thematic role assignments based solely on semantic factors. That is, even for the simplest type 1 structure (e.g., "the boy that had red hair carried the girl") it is still the case the either the boy or the girl could plausibly be an agent or patient of carry, and either could have red hair. For sentences without this possibility of role reversals (e.g., "the apple that the boy ate was red"), there may be no tendency to carry out such a check using a verbatim backup representation. A similar situation of obviating the need for a backup may apply even for sentences with reversible structures when these structures are embedded in a discourse context that strongly biases the role interpretation of nouns and adjectives (e.g., a scenario with one little boy (of several) twisting his ankle and an older girl carrying him home – "the boy that the girl carried was very grateful"). Only future research could address these possibilities regarding when use of a phonological record plays a role.

In sum, these data provide strong support for the role of semantic WM during relative clause sentence comprehension for sentence types argued to make heavy demands on WM relative to matched sentences with lesser demands. Phonological WM also played a role; however, the nature of its contribution is unclear as it occurred across sentence types, irrespective of structural demands. Future work will be needed to investigate the function of phonological WM across sentence types.

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